QUANTIFICATION OF SUSPENDED SOLID TRANSPORT IN THE ENDJA WATERCOURSE [DEHAMECHA BASIN-ALGERIA]

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ABSTRACT

The Dehamecha watershed is one of the most degraded basins in Algeria. This basin suffers from strong water erosion, especially during floods, where sediments are transported by the Endja watercourse draining it and depositing them in Beni-Haroun dam. Based on data series provided by the National Water Resources Agency of Constantine concerning the Tassadane gauging station, a correlation is made between two data pairs: suspended material concentrations and liquid flow C-Q_l, solid flow and liquid flow Q_s-Q_l. On a monthly scale, the exponential model is the most suitable for the first correlation and the power model for the second one. Based on these two mathematical models, the quantitative estimation is obtained by identifying the average specific erosion rate over a 30 years' period, which exceeded 1000 tons / km^2.year. The extreme events (floods) have a predominant role in the export of large sediment volumes.

1 INTRODUCTION

Diverse sedimentological aspects of watersheds have been analyzed by several authors, regarding their size, substratum and hydrological regimes [1, 2, 3, 4, 5, 6]. Soil erosion is sensitive to many factors such as land use, geology, rainfall distribution and intensity, and pedology [7, 8, 9, 4]. The essential role of extreme events on long-term sediment transport is highlighted [10], as well as a wide variability of watershed erosion at spatial and temporal scales [11, 12, 13, 14, 15].

The erosion, transport, and sedimentation cycles are particularly important for Mediterranean and tropical environments even on very low slopes [16]. In these areas, rainfall is characteristic of irregularity and high intensity. This leads to clumps stripping and their fractioning into aggregates or elementary particles by rain and runoff slacking; or also by bursting of aggregates during wetting. Soils are more vulnerable to runoff and water erosion [18] if their surface is not protected by litter or vegetation cover [17, 18].

Numerous studies have been conducted worldwide to quantify the suspended load transport during unique flood events [12], as well as dams filling estimate with fine materials [19, 20, 13, 21, 22] and to track seasonal and spatial variations in suspended matter concentration in contexts, various morphoclimatic conditions [8, 1, 23, 10, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 21, 34, 15, 35].

Rivers appear as an integrator of their hydrographic basin's denudation, when it is reduced to a surface (basin watershed), it is called specific denudation and expressed in t.km-2.an^{-1} or mm/millennium (or per year). Denudation is estimated via exported flow measurement which is done according to three transport modes: in solution, in suspension, and bed load transport, while the latter occurs through material progressing by rolling and/ or saltation on river bed [36].

In Algeria, erosion rate exceeds 2000 t/km^2.year on most of the Tellian Atlas catchment areas. It reaches 4000 t/km^2.year on Dahra coastal chain and 5000 t/km^2.year on the much degraded Agrioum watercourse basin [37], the most dramatic consequence of which is undoubtedly reservoirs' siltation. Currently, there is an accumulation of more than 650 10^6 m^3 of silt in more than 110 Algerian reservoirs. The Beni-Haroun reservoir, one of the major works in Algeria with a storage capacity of 795 hm^3, receives every year enormous quantities of sediments transported by the neighbouring watershed rivers. The Dehamecha basin, which makes part of the Kebir-Rhumel basin and which is severely degraded, also contributes to the reservoir's supply by significant amounts through the Endja watercourse.

This study basin (Dehamecha) was chosen because of the huge rainfall falling over its area, as well as its morphological characteristics that aggravate the runoff and water erosion phenomena. The initial objective of this research was to quantify the sedimentary load and determine the erosion rate of the Endja watercourse draining

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the Dehamecha watershed, as well as highlight the role of extreme floods in suspended solids export. All this was considered while studying the relationship between the two data pairs: liquid flow-solid flow (Q_l-Qs) and liquid flow-suspended sediments (Q_l-C) for: the all data, wet season, hot season and for the monthly scale. The choice of the appropriate mathematical model allowed us to correctly quantify the solid contributions as well as erosion rates over the entire study area.

The study data: rainfall, liquid flows and suspended solid concentrations are provided by ANRH (National Water Resources Agency) -Constantine- for "Tassadane" hydrometric station which is the only station controlling the Endja watercourse. All maps are provided by ABH (Hydrographic Basins Agency) at Constantine.

2 STUDY AREA

Our study area is made up of three sub-basins: Dehamecha-Kebir watercourse upstream, Kebir upstream-Endja, and Rhumel watercourse upstream, which make part of the Kebir-Rhumel basin, stretching between the Mediterranean Sea and salt-lakes high-plains in the south (Fig. 1). The basin has a total area of 3399 km^2 and average altitude of 738 m; the sectors higher than 1200 m altitude correspond to large and extensive mountain ranges in the area, while those of altitude below 600 m, represent the low hills (Fig. 1).

The entire study area is drained by the Endja watercourse, which is controlled by one hydrometric station "Tassadane". A sufficient number of data (liquid flow, solid flow and suspended matter concentrations in this station) were obtained to develop a fine-tuned study of the flow regime, thus showing the suspended sediment load quantification and the erosion rate of the studied watershed.

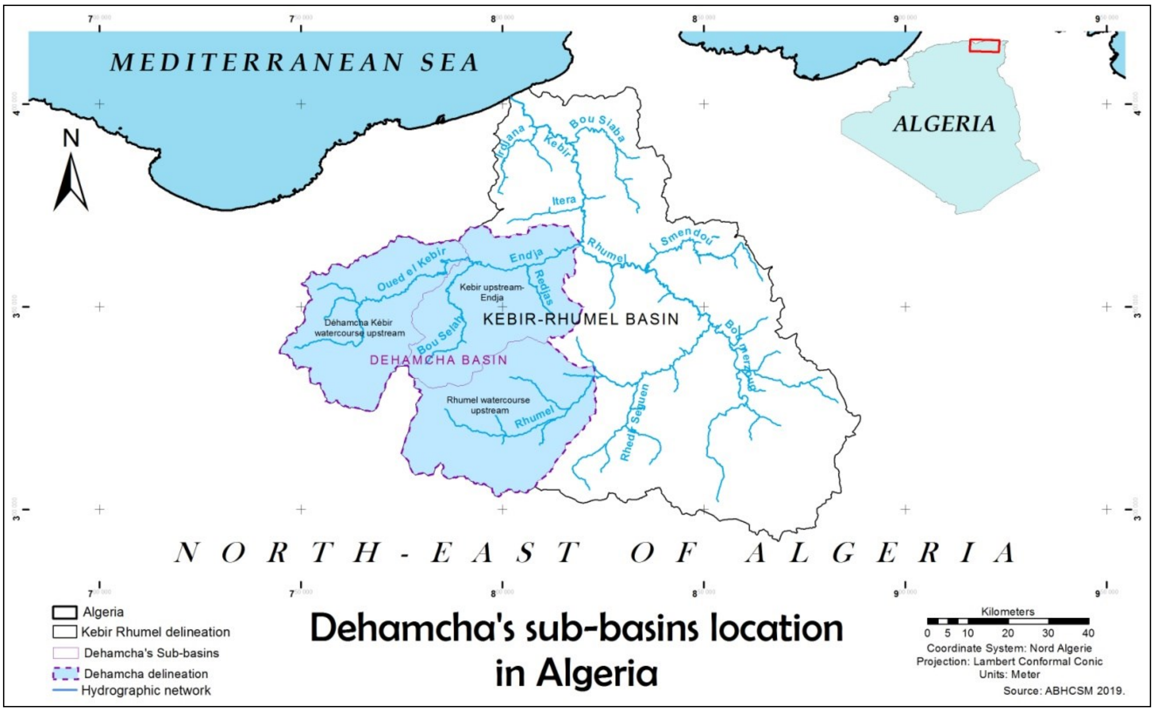

Figure 1. Dehamecha sub-basin location in Algeria (modified according to ABH-Constantine, 2019)

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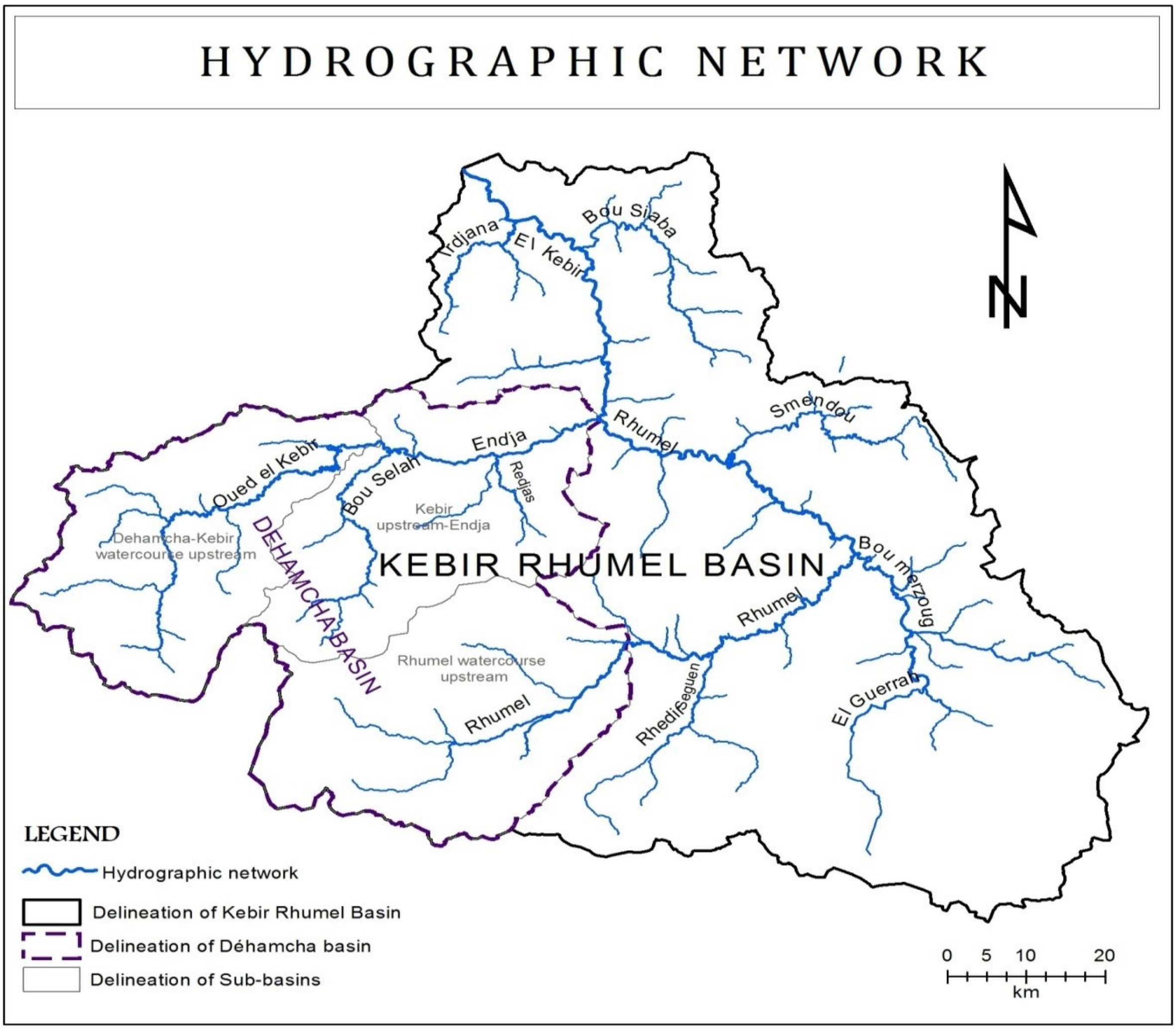

Figure 2. Hydrographic network location in Algeria (modified according to ABH-Constantine, 2019)

The Kebir-Rhumel watercourse is the junction of two major watercourses: Rhumel watercourse and Endja-Wadi, where the confluence gives birth to Kebir-Wadi. The Endja watercourse that drains our study area is made upstream from the Dehamecha watercourse and the Menaa watercourse confluence, the first taking its source at the high plains limit, north of El-Eulma, the second around Ain-El-Kebira, in Petite-Kabylie massifs. The Endja watercourse does not receive any important tributaries on its left bank, while on its right bank, it collects the Rarama (or Djemila), Bou-Saleh and Redjas-El-Melah river waters (Fig. 2).

3 STUDY AREA MORPHOLOGY

3.1 Geological structure

The Dehamecha basin is almost totally located in the Kebir Rhumel basin; it extends in the southern Tellian piedmont and in the northern Tellian massifs. The South-Tellian piedmont corresponds to Constantine Neogene basin that extends to west by Djemila water ground. Constantine Neogene basin is a large mio-Pliocene depression extending from Ferjioua in the west to Zighoud Yousef, in the east, bounded by high plains to the south. These are low hills (500-600 m) with soft forms. This vast lake basin contains of some isolated limestone reliefs corresponding to Tellian series. Djemila Tellian water ground includes marly or clay formations of late Cretaceous-Eocene age, dominated locally by series of limestone or marly-limestone [37].

The Northern Tellian massifs correspond to the Numidian chain, which is mainly composed of Jurassic limestone massifs and Oligocene sandstone massifs. These reliefs form an imposing rocky barrier that shares the small Kabylie of El Milia in the north and the Constantinois in the south. The calcareous massifs, affected by a complex tectonic, break in the form of thick layer scales with dominant marl. They are covered at some areas by the bed load of Kabyle base [37].

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In these steeply sloped areas, the erosion processes have, depending on the land lithological nature, a greater or lesser extent. The phenomena leading to scree formation are frequent, limestone detachment and especially sand stone blocks occur both due to gravity or sliding. In fact, it is not uncommon to observe niches of fresh cuttings, as on slopes located at Beni-Haroun clause entrance [37].

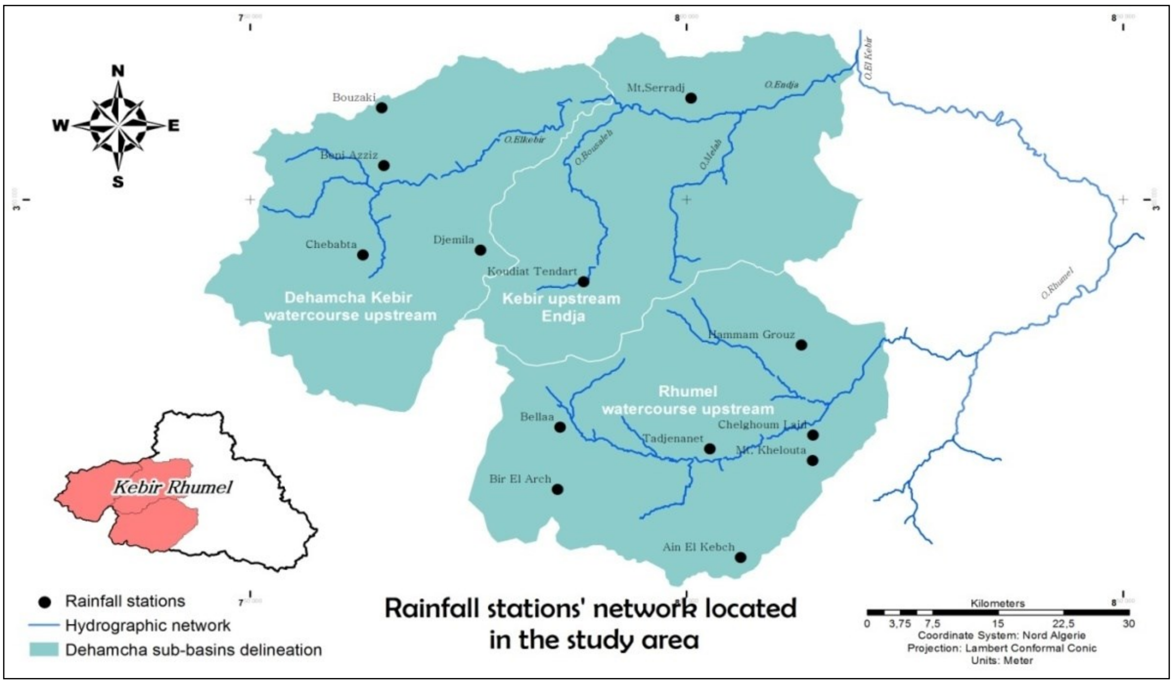

Figure 3. Rainfall stations network located in the study area (modified according to ABH-Constantine, 2019)

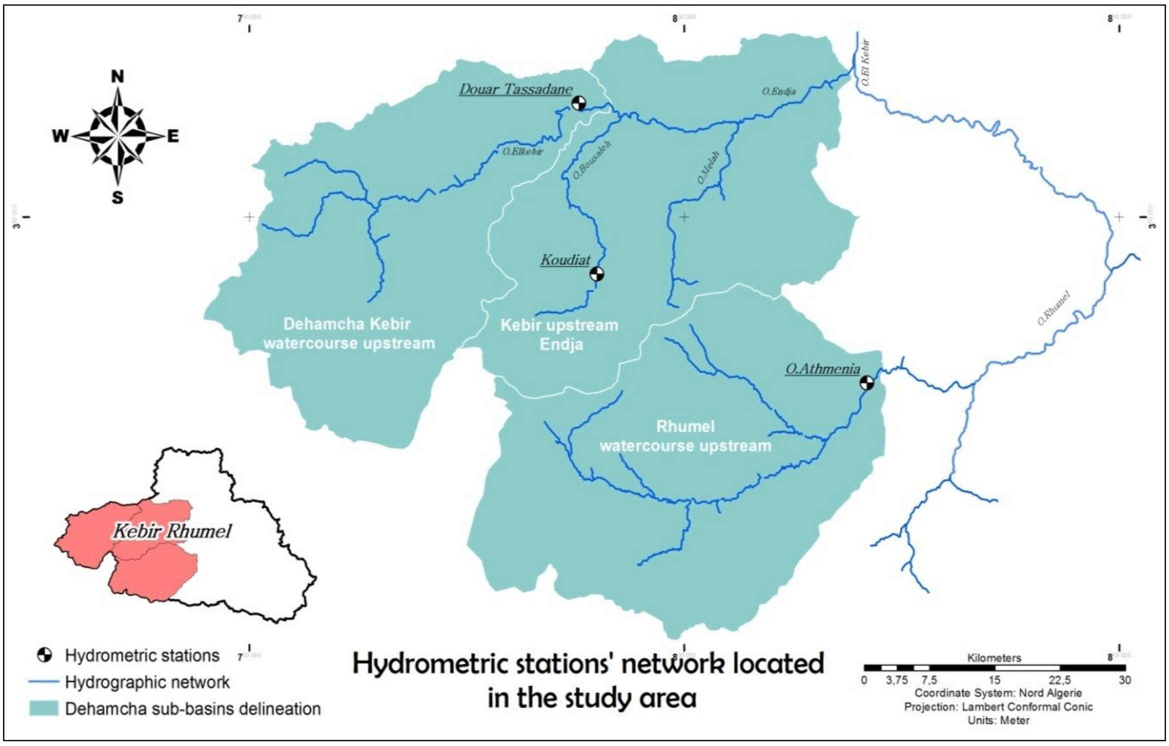

Figure 4. Hydrometric stations network located in the study area (modified according to ABH-Constantine, 2019)

3.2 Hydrologic unit surface, altitude and form

The Dehamecha basin has a total area of 3399 km^2, formed by three sub-basins: 10-01, 10-02 and 10-03 called "Oued Dehamecha-Kebir upstream" of 1067 Km^2, "Oued Kebir upstream-Endja" of 1102 Km^2 and "Oued

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Rhumel upstream" of 1230 Km^2 of surface area. The watershed average altitude is about 738 meters. Sectors of altitude higher than 1200 m are rare in the study area, they correspond to important mountainous massifs belonging to the Numidian chain (Northern Tellian massifs) and Djemila Tellian water ground (South Tellian Piedmont) which exceed the altitude of 1600 m. Sectors of altitude lower than 600 m, representing 26.2 % of the basin total area, correspond to low hills located in Constantine Neogeneous basin.

Basin shape expressed via Gravelius compactness index has also a certain influence on the flow. In certain measures, it determines the flood hydrograph pace: a very elongated basin will not react in the same way as a compacted one [38]. The Dehamecha basin compactness index value is about 1.14, showing a rather high compactness, with a fairly compact shape favouring, a priori, the runoff water content time. Tab. 1 represents the morphometric characteristics of the study area (three sub-basins).

Table 1: Morphometric characteristics of three sub-basins [37]

Basin	Perimeter ″P″ (Km)		Average altitude (m)	Minimum altitude (m)	Max altitude (m)	C	Relief class
	Actual	Stylized					
Oued Dehamecha-Kébir upstream	374	314	806	150	1729	1.21	Moderated relief
Oued Kébir upstream-Endja	150	125	929	380	1662	1.14	Strong Relief
Oued Rhumel upstream	156	140	913	700	1276	1.17	Moderated relief

Explanations: C=Gravelius compacity index.

4 LAND COVER IN THE STUDY AREA AND ITS INFLUENCE ON WATER EROSION

From the hydrological point of view, vegetation shall not be considered through its land cover aspect or its botanical or phyto-geographic ones, more or less modified by humans. In fact, it is land cover density that intervenes as a differentiation element in terms of both flow and soil degradation level. Therefore, it seemed useful to adopt vegetation types classification according to the decreasing density or efficiency, proposed by Tricart [36]. Its application to our study area allows distinction of permanent well-protected surfaces, thus unfavourable to runoff and water erosion represented by forest formations.

Forest vegetation cover is low in the basin. It is mainly located on the wettest and coolest summits, cork oak is relayed by *Quercus mirbecki* or *Quercus afares* as well as permanent natural and artificial prairies. Areas partially protected by vegetation cover, represented by "seasonal" vegetation such as cultivated land, cereals and vegetable crops, which occupy the soil only for a part of the year and largely dominate the area, especially from north to south. Dominance of huge "open" fields coexist with deforested massifs in the basin, which favours concurrently materials' runoff and entrainment phenomena following intense showers. These are even more significant regarding slope power. Their spatial and temporal discontinuity increases from north to south, as rainfall decreases [37].

Poorly protected or bare surfaces, such as the bare land, steppe, coppice and brushes with low density, suffer from runoff and water erosion. Tab. 2 shows the distribution of land cover types in the study area elaborated by Demmak [37].

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Table 2: Distribution (%) of land cover types in the Dehamecha basin [37]

Basin	1. Well protected areas		2. Non protected areas		3. Bare or poorly protected areas
	Forest-maquis	Natural and artificial prairies	Groves (with extensive dominant)	Cultivated lands (cereals, vegetable crops, etc.	Bare surfaces, steppe, brushes
Dehamecha	12.0	1.4	1.7	53.9	31.0

Apart from the narrow wooded band, which is a kind of rain-reducing filter, in the study area remaining area, materials draining by threshing is favoured by vegetation cover absence during much of the year regarding croplands, mainly grassland, or by its low cover land density, through the total absence of bare rock. Vegetation types distinction according to either their soil protection efficiency or permanent or seasonal nature is valuable in the study of vegetation cover influence on water erosion.

These conditions are frequently met in the study area, especially in bare mountainous areas, almost totally bare, drained by the Endja watercourse. The turbidity measurements for Tassadane hydrometric station are good indicator of water erosion effectiveness [37].

5 METHODS

Starting in the 1970, the measurements of the solid transport in suspension have been extended on the whole national water network of Algeria by the services of the ANRH, thus allowing a counting of a large number of data in order to undertake a general study on erosion, solid flows and siltation of dam reservoirs.

Our database contains instantaneous measurements of liquid flows Q_l in (m^3/s), solid flows Q_s in (kg/s) and suspended sediments concentrations C in (g/l) carried out by the ANRH services (National Water Resources Agency) of Constantine for the Tassadane station located upstream of the Beni Haroun dam. These measurements cover a 30-year period from 1973 to 2003.

Liquid flows are obtained in two ways: by the calibration curve from the water depths read on a limnimetric scale and by stripping of depths water recorded by a float limnigrapher [39].

The solid transport samples are taken at the edge of the Oued according to a protocol for measurement and determination of the solid load established on the national territory [39], then they are analyzed in the laboratory by the ANRH services.

At each water level measurement, a sample of charged water is taken from the shoreline at the surface of the water using a 50 cL vial. At each collection, samples are transferred to plastic bottles and stored in a cooler at low temperature (T = 4°C). The samples are then returned to the laboratory for analysis. The water is filtered to collect suspended solids on Whatman filter paper (filter porosity 10 µm, filtration time t = 10.5 s). The filters are then dried in the oven (for 30 minutes at a temperature of 105 °). When reduced to the unit volume (1 litre), the suspended load is then calculated by the following relationship:

$$C = (P2 - P1)/V \tag{1}$$

where

C is the concentration expressed in (g-L 1)

P1 is the weight of the dry and empty filter paper expressed in grams before weighing the sample.

P2 is the weight of the filter paper with suspended sediments expressed in grams.

V is the volume of the sample.

This measured solid load is attributed to the instantaneous concentration of suspended solids transported by the watercourse in (g-L 1). The number of samples has been adapted to the hydrological regime. These are carried out every other day. During flood periods, catches are intensified up to one-hour or even 30-minute intervals depending on the speed of the increase in liquid flows.

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The flow rate of suspended solids is therefore the product of the concentration estimated in kg-m 3 by the corresponding liquid flow rate measured in m3-s 1 [40]. The solid flow is calculated by the relation: $Q_s=Q_l*C$ where Q_s is the suspended solid flow (kg/s); C is the concentration of suspended sediments (g/l); and Q_l is the liquid flow (m^3/s).

In fact, the sediments mass in the sample does not represent all the materials set in motion by the overall dynamics affecting the watershed. The specific solid transports resulting from these concentrations do not take into account base loads; solution transports; variations in suspended solids content from one point to another in the wet section, particularly during flood periods that make sampling dangerous for the observer [41].

After having collected the data base, one proceeds to data processing, followed by statistical treatment of the series of variable each separately: Q_l, Qs and C. Finally, we classify all the data into two pairs: liquid flow - solid flow and liquid flow - concentration, for: totality of the data, wet seasons, dry season, and on monthly scale, in order to study the representative mathematical models for each pair of data.

Exceptional events data (floods) are provided by ANRH in a separate file containing: date, time, water level in (cm) and corresponding liquid flows for a 30 years' period from 1973 to 2003. This makes it possible to identify the most powerful floods in the export of solid inputs.

Figures 5 - 24 were drawn by the authors based on the data provided by the Constantine National Water Resources Agency.

6 RESULTS AND DISCUSSION

6.1 Rainfall analysis

In the studied basin, rainfall increases from south to north; the average rain variation is from 318 mm in the south basin to 1000 mm in the north.

The Dehamecha basin is provided with seven rainfall stations (Hammam, Koudiat, Belaa, Bir el Arch, Ain El Kebch, Mechta, and Chelgoum) and controlled by the ANRH-Constantine where their statistical characteristics are shown in Tab. 3.

Table 3: Annual precipitation (mm) at different studied rainfall stations: Hammam, Koudiat, Belaa, Bir el Arch, Ain el Kebch, Chelgoum

Station Code	100110	100208	100302	100306	100307	100308	100312
Year /Station	Hammam	koudiat	Belaa	Bir el arch	Ain el kebch	Mechta	Chelgoum
Maximum	750.82	680.89	828.90	464.50	509.30	721.92	624.70
Minimum	228.60	232.20	131.60	142.50	120.30	132.88	123.07
Average	405.70	450.34	396.56	304.76	272.16	374.29	371.16
Median	390.70	434.35	370.80	308.70	258.94	355.82	362.31
Balance	14425.31	13660.39	28956.60	7492.33	9365.96	15257.97	13090.25
Variance type	120.11	116.88	170.17	86.56	96.78	123.52	114.41
Asymmetry index	0.78	0.12	0.87	-0.02	0.69	0.35	-0.01
Flattening index (kurtosis)	0.40	-0.95	0.19	-1.20	-0.03	0.08	-0.22
Variance index	0.,30	0.26	0.43	0.28	0.36	0.33	0.31

Due to precipitation's major role including their monthly and seasonal distributions, as well as showers that generate floods on rivers hydrological regime behavior, a precipitation study of over the entire study area has been carried out, for which data were supplied from seven rainfall stations (Fig. 3). Rainfall series were about 40 years of measurement, spread between 1970 and 2010.

Precipitation analysis is carried-out by ACP principal component analysis. It is a method that reduces a variable number to allow the geometric representation of the observations and studied variables. This reduction is only possible if initial variables are not independent and have non-zero correlation coefficients [42].

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The application of the principal component analysis (PCA) method in the study basin shows that the rainfall stations: Koudiat, Ain el Kebch, Chelgoum and Belaa have large C_1 vector values (0.89 and 0.88) successively. Consequently, we can consider Koudiat stations as a representative station of the study area (Fig. 3).

To better understand the precipitation's inter-annual irregularity, which plays an essential and decisive role on flow, and to characterize the annual precipitation regime in the Dehamecha basin, graphically through (*PCA)* analysis we have presented the studied station el Koudiat observations projection during the period 1970-2010 for the first (C_1) vector (Fig. 5).

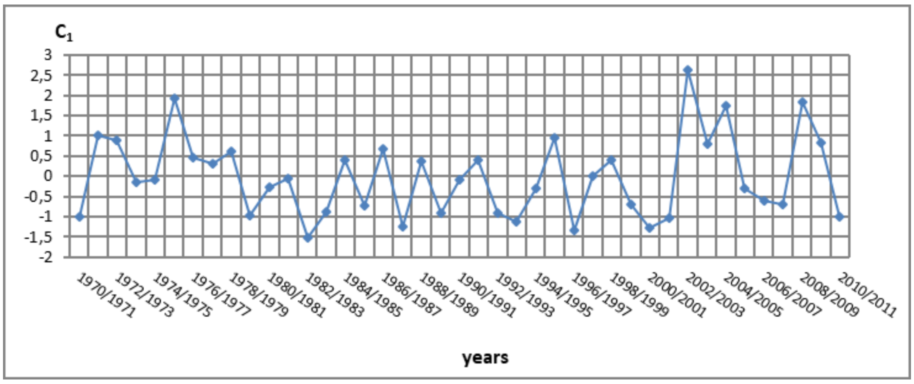

Figure 5. Rainfall observations projection on the first component (C_1) in the Dehamecha basin

The largest observed values of regional vector (C_1) correspond to wet years (1977, 2003, 2005 and 2009) as long as low values correspond to dry years (1983 and 1997). During low hydraulicity years, the quantity of exported suspended sediments is relatively small and distributed almost homogeneously throughout the year [14]. In relation to thermal factors, precipitation monthly distribution will condition seasonal flows and there by river regime, soil erodibility and suspended material transport.

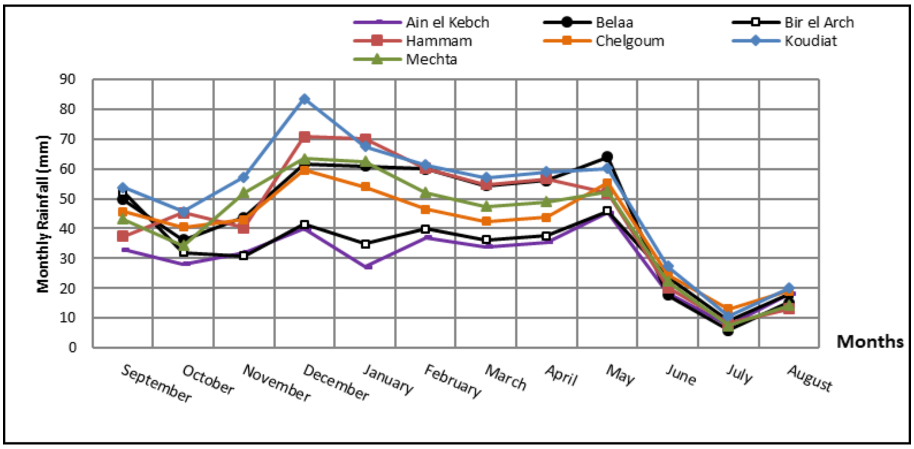

Figure 6. Monthly rainfall variation in the Dehamecha basin

For the seven studied stations in the study area, two periods were distinguished (Fig. 6);

- A dry period corresponds to summer season (June, July and August) and is characterized by a marked rainfall deficit.
- A wet period corresponds to the rest of the year. These rainy periods are also marked by a succession of wet months and relatively dry months.

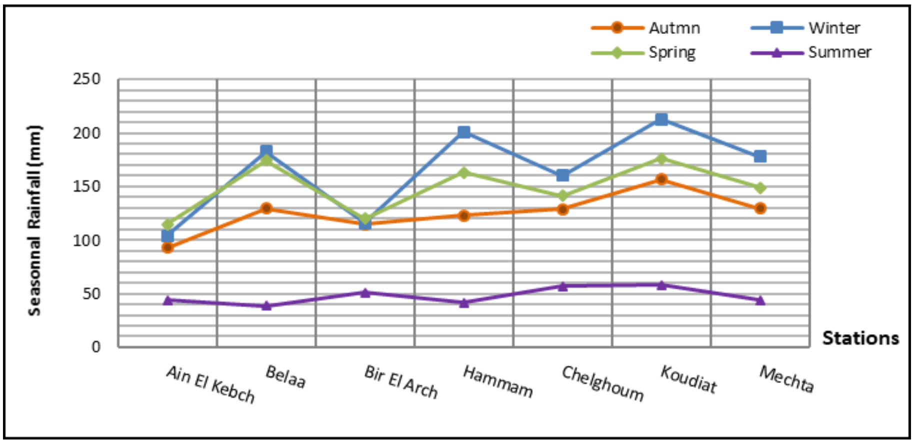

Figure 7. Seasonal rainfall variation in the Dehamecha catchment area

The monthly rainfall distribution shows rainfall ranging between 104 mm and 212 mm, 93 and 156 mm, 114 mm and 176 mm, and 38 mm and57 mm in winter, autumn, spring and summer season, respectively. The difference in season's rainfall totals is very remarkable. The majority of minimums are recorded at Ain-El-Kebch station, while maximums are recorded at El-Koudiat station (Fig. 7).

6.2 Flow analysis

The data provided by ANRH-Constantine for Tassadane hydrometric station (Fig. 8) regarding flow rates were studied for a period of 30 years from 1973 to 2003.

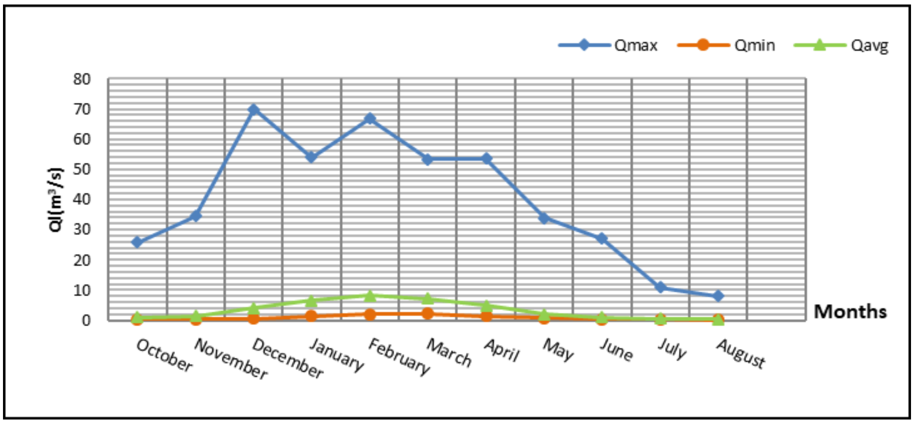

Figure 8. Inter-annual flow variation (Q_{max}) (Q_{avg}) and (Q_{min}) in the Dehamecha basin

Fig. 8 shows a wide interval between maximum, average and even minimum flow rates. Flows can reach 70 m^3/s, while the average flow does not exceed 20 m^3/s, which is related to the significant effect of extreme events.

6.3 Floods hydrograph

The major role of floods in sediments and pollutants transfer associated with particulate phase has been demonstrated in case studies [44, 45]. In the Mediterranean area, floods are also considered as the key moments in sediments and associated contaminants' transport [46, 47]. To highlight the below reaction: studied basins opposite to maximum extreme flows generated by showers where rainy sequences generate floods; we have graphically represented hydrographs of 38 studied floods spread over 30-year period from 1973 to 2003, 18 of which belong to wet season and 20 to dry season (Fig. 9 and 10).

To visualize a large number of recorded data, we presented the instantaneous liquid flow variations in two Figures. Fig. 9 shows data from 25th/09/1973 to 16th/01/1986, while Fig. 10 from 16th/01/1986 to 21st/08/2003.

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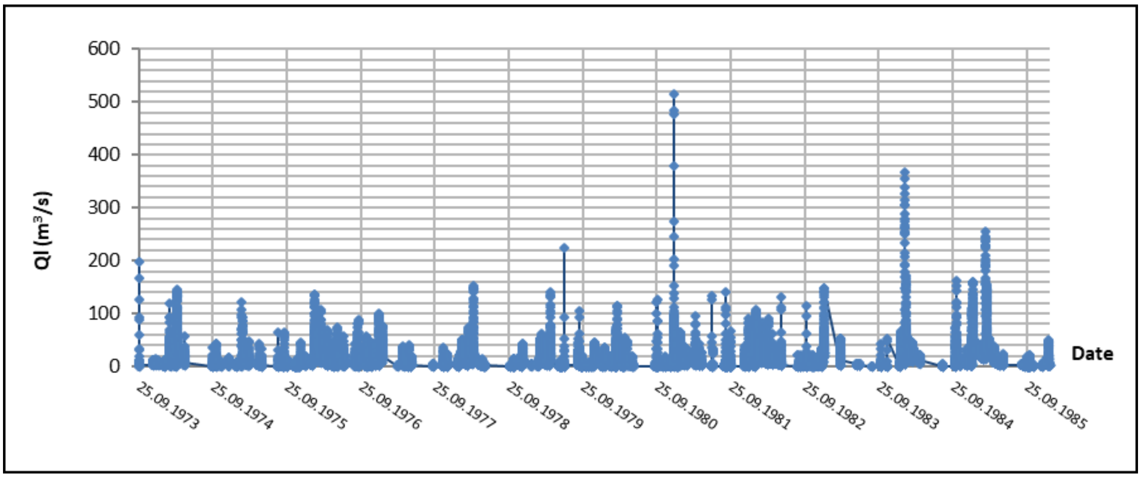

Figure 9. Overall floods in the Dehamecha basin from 25/09/1973 to16/01/1986

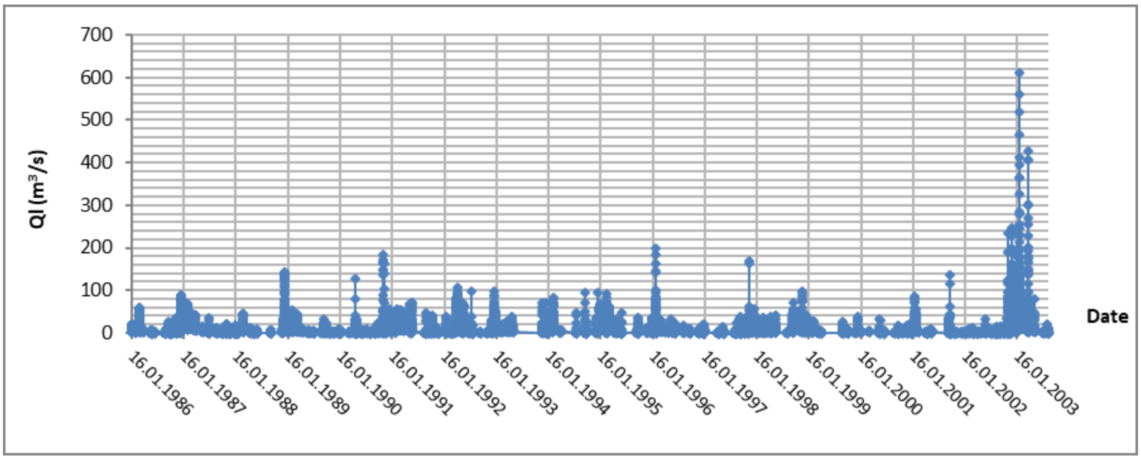

Figure 10. Overall floods in the Dehamecha basin from 16/01/1986 to 21/08/2003

To define correctly each flood type character, we have presented two standard floods; one of wet season that was recorded from 3th to 4thFeb/1984, while the second is of dry season, recorded on 25th/Sep/1973. These two floods were chosen as they are the most representative of both wet and dry seasons regarding their temporal and spatial characteristics (genesis, propagation mechanisms, power, duration, frequency, etc.).

We have actually represented the liquid flow as a function of time.

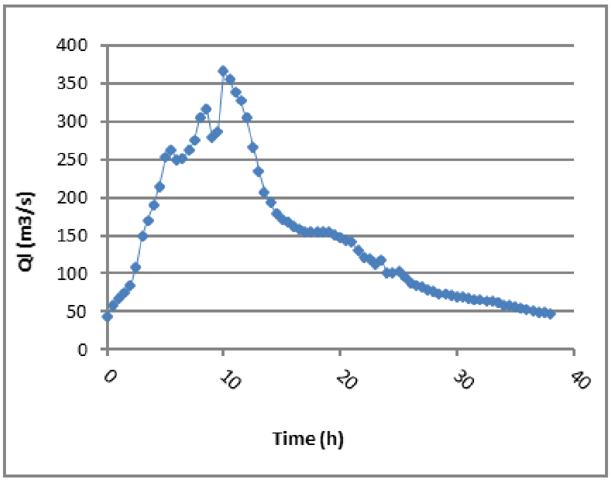

Figure 11. Flood of 3rd-4th/Feb/1984 in the Dehamecha basin

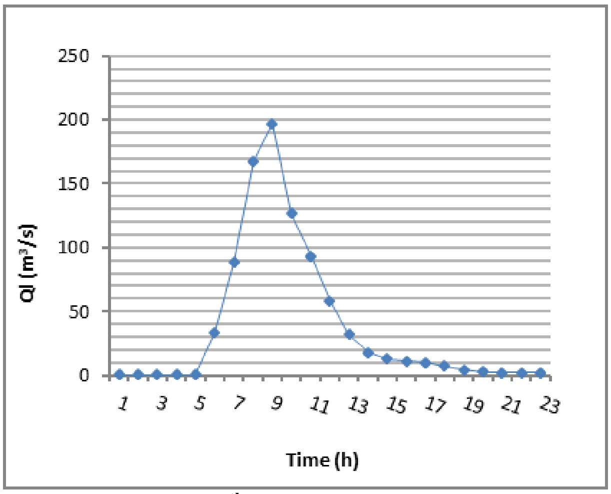

Figure 12. Flood of 25th/Sep/1973 in the Dehamecha basin

Wet season floods are generated by showers that are both long-lasting and extensive, sometimes affecting all or a large part of the study area. These showers can generate several peaks called "complex showers", unlike water rise; water fall was done much slower (Fig. 11). Dry season floods are generally associated with brief and localized thunderstorms [37], which are characterized by a duration and spatial extension shorter than wet-season floods. Their hydrograph is characterized by a sharp rise, as long as the water fall is also rapid due to rainfall stoppage after flood peak (Fig. 12).

One of Mediterranean climate features is to produce flash floods (short-lived violent floods) during which the bulk of sedimentary exports occur. Their power is also lower, although sometimes, as a result of torrential showers, they can reach unprecedented proportions during periods of high water, resulting in sudden flooding. Indeed, these two major types of floods are different, through their genesis and propagation mechanisms as well as their power, duration, frequency, and geographical extent [37].

6.4 Suspended solids evaluation

Two correlation methods are used. The first is to evaluate the suspended material concentrations via the relation $C=f(Q_l)$. For this case, the monthly distribution showed that the exponential model $C=x\,e^{yQl}$ is the most adequate with correlation coefficients that can reach 0.84. For the second mode, we relied on flood series providing liquid flows and the corresponding suspended sediments are used. Having underlined "well-observed floods", using relation that gives solid flows values from liquids ones: $Q_s=f(Q_l)$, and for a monthly distribution, the power model $Q_s=A.Q_l^B$ is the most suitable with a correlation coefficient ranging from 0.70 to 0.90.

C: suspended sediments in g/l, Q_s: solid flow in kg/s and Q_l: liquid flow in m^3/s.

According to (Q_l-Q_s) couple models found previously on the monthly scale, we quantified the suspended solids inputs by applying the corresponding model for each month, then we can obtain Q_s every year, for the two cases: solid flow with flood (without elimination of flood volumes) and solid flows without flood (by elimination of flood volume) to predefine the extreme events role in solid inputs export.

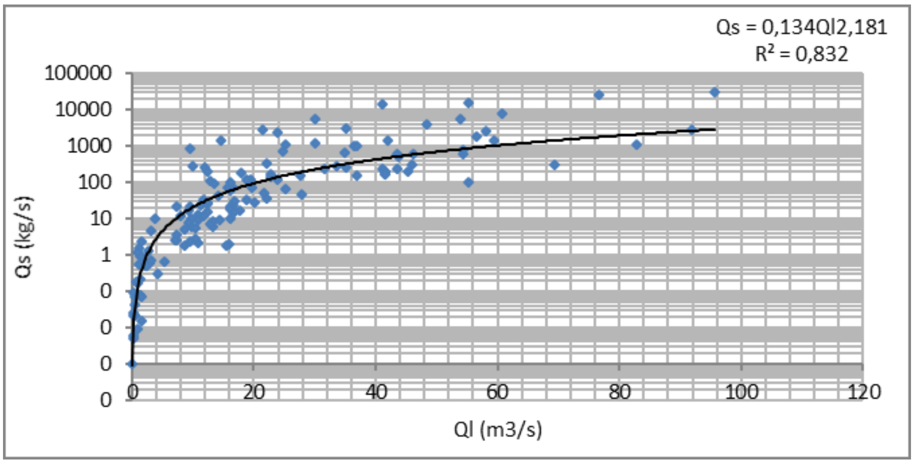

Figure 13. Solid flows variation according to liquid flows concentrations in the Dehamecha basin

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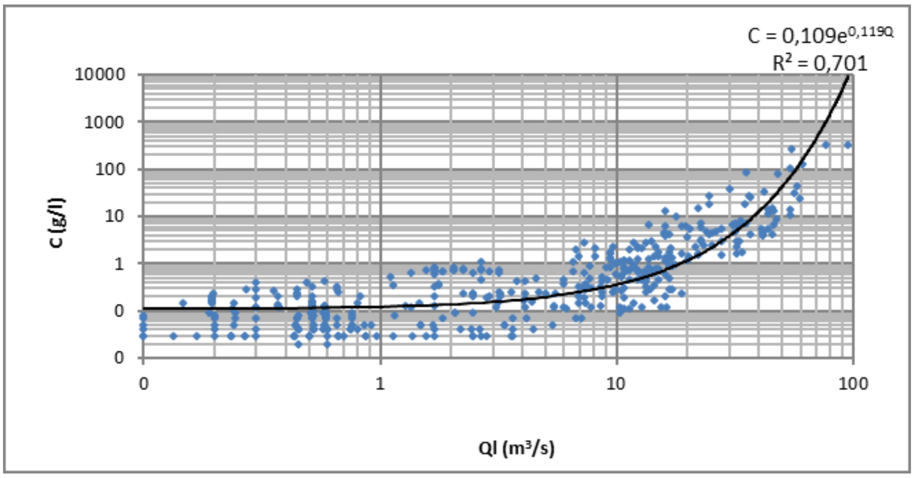

Figure 14. Suspended sediments variation according to liquid flows in the Dehamecha basin

A visualization of all observed data, in a diagram for Q_s-Q_l couple (Fig. 13), showed the trend of the power curve, with a determination coefficient R^2 = 0.83; while for C-Q_l (Fig. 14), the exponential model is the most suitable for dataset with a determination coefficient R^2 = 0.70.

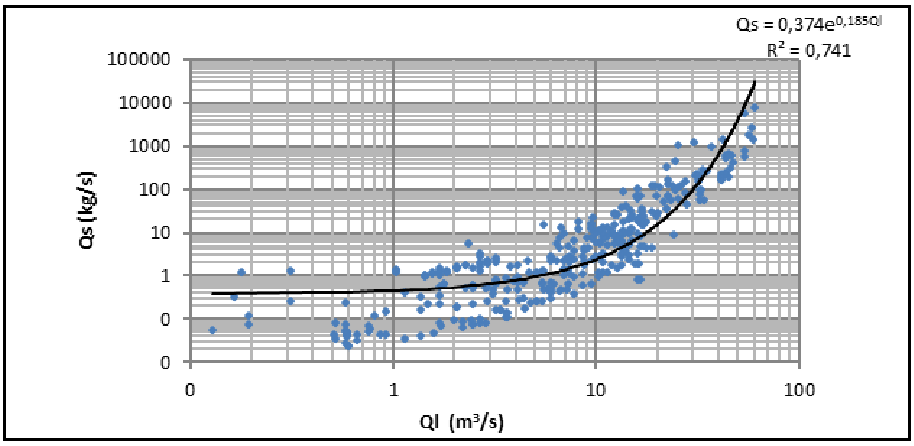

Figure 15. Solid flows – liquid flows variation for the wet season in the Dehamecha basin

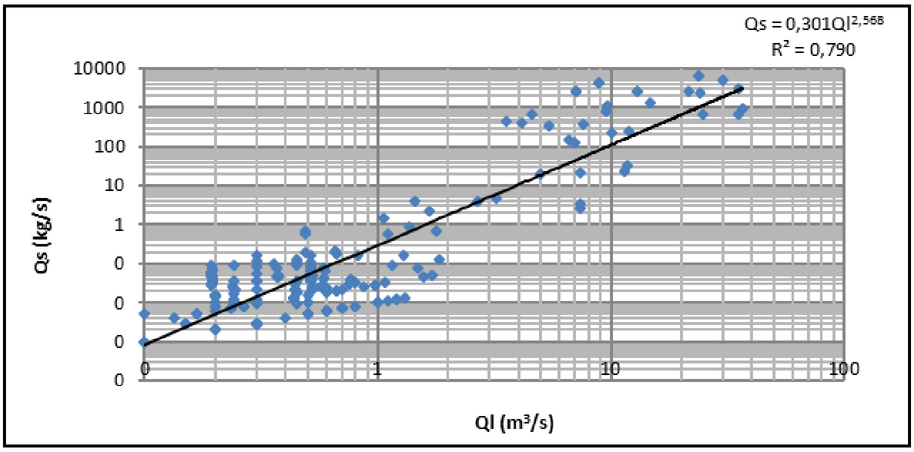

Figure 16. Solid flows – liquid flows variation for the dry seasons in the Dehamecha basin

Visualization of all data for liquid and solid flows for wet season shows good exponential trend with a correlation coefficient of about 0.74 (Fig. 15), while that of dry season, the model power is the most adequate with an excellent correlation of about 0.79 (Fig. 16).

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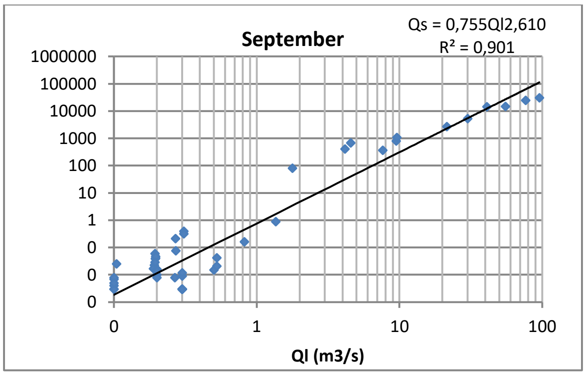

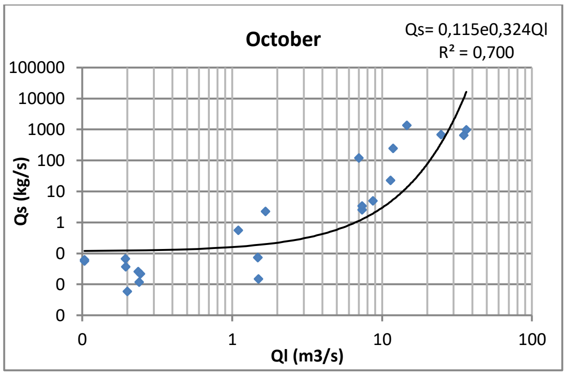

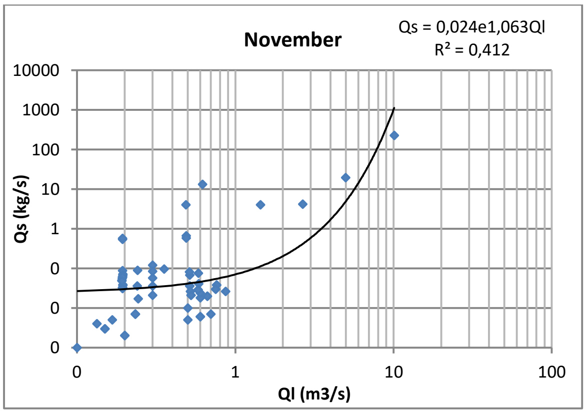

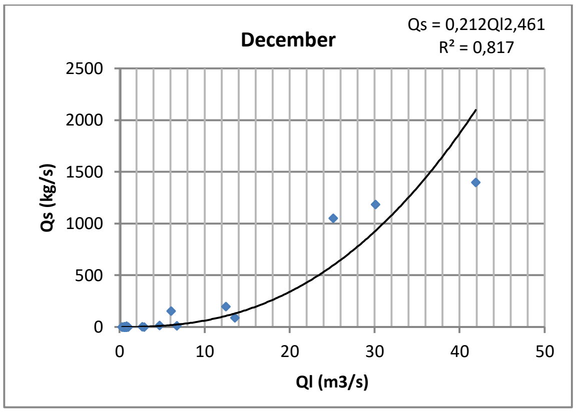

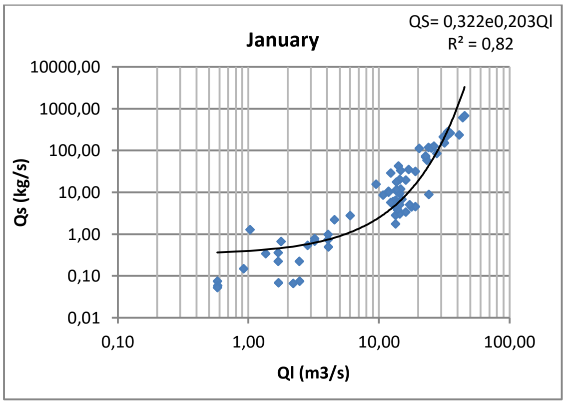

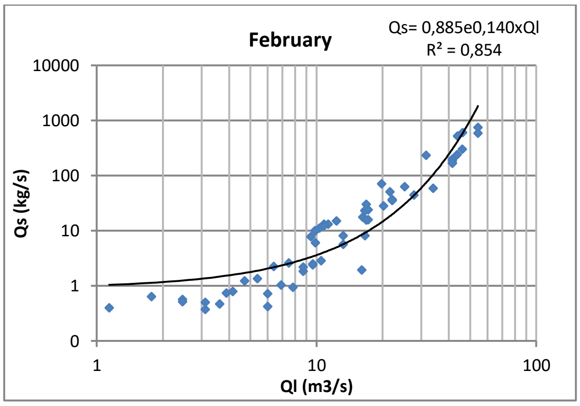

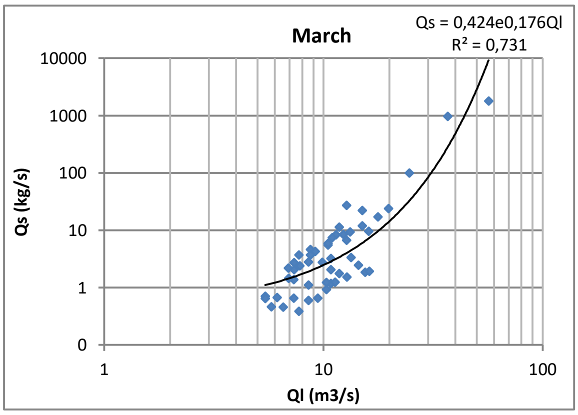

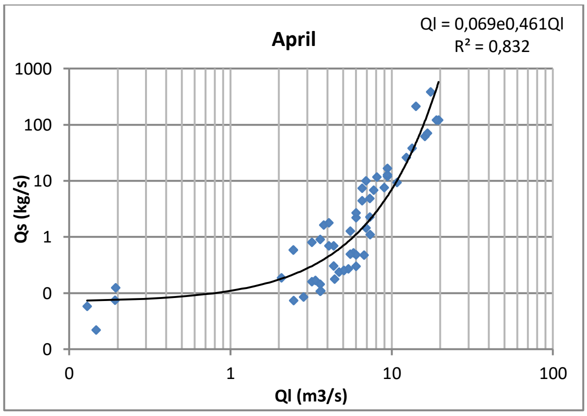

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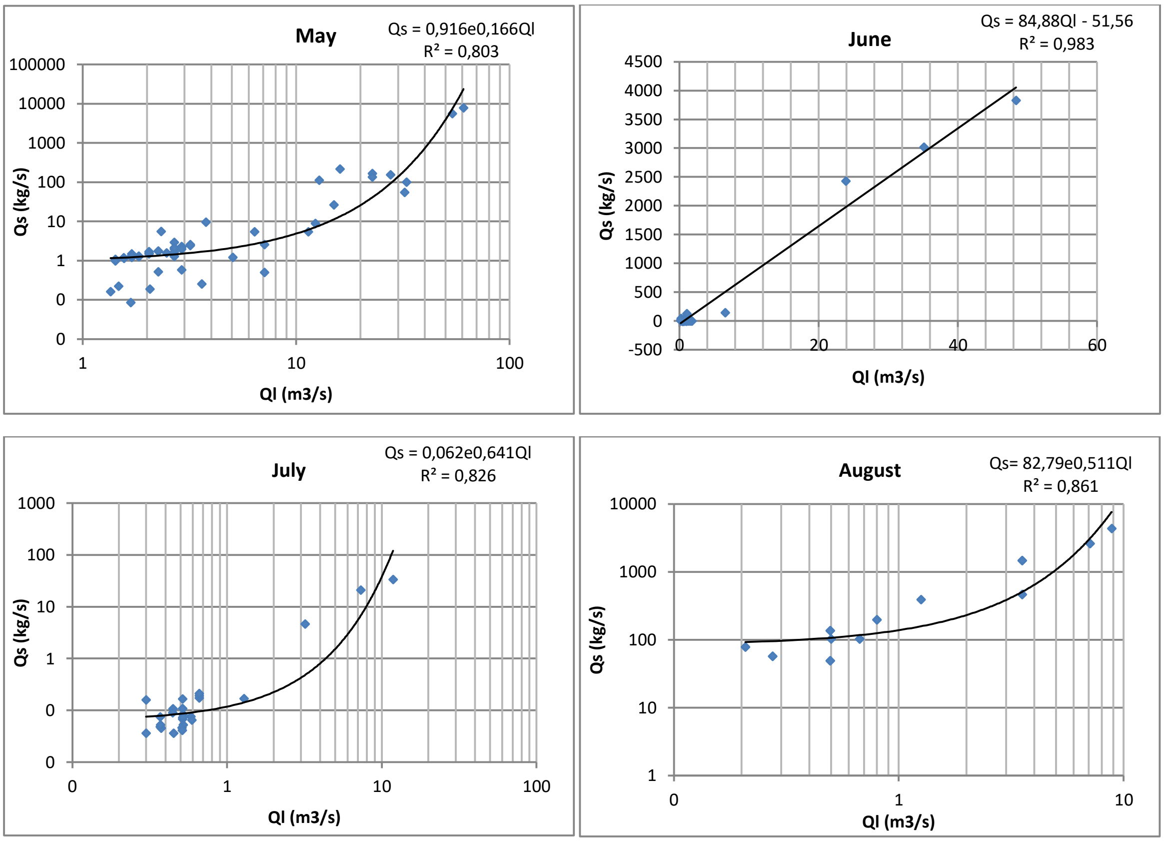

Figure 17. Solid flows – liquid flows variation for the monthly scale in the Dehamecha basin

Visualization of liquid and solid flows data on the monthly scale in Tassadane station shows a trend with a correlation coefficient which varies between 0.70 in October to 0.98 in June (Fig. 17). The exponential model is the most dominant.

Each month is characterized by a specific form characterizing the variation of the solid contributions according to the liquid contributions; this variation informs us about the limits that reach the couple (Q_S-Q_l). The results of solid and liquid flow correlation for the monthly scale are presented in Tab. 4.

Table 4: Models retained and their coefficients of determination calculated for the monthly scale

Month	Type of model	Model retained	Coefficient of determination (R^2)
September	Power	$Qs=0.755*Ql^{2.61}$	0.90
October	Exponential	$Qs=0.115e^{0.324Ql}$	0.70
November	Exponential	$Qs=0.023e^{1.004Ql}$	0.72
Décember	Puissance	$Qs=0.212*Ql^{2.461}$	0.82
January	Exponential	$Qs=0.322e^{0.203Ql}$	0.82
February	Exponential	$Qs=0.885e^{0.14Ql}$	0.85
March	Exponential	$Qs=0.42\ e^{0.176Ql}$	0.73
April	Exponential	$Qs=0.069e^{0.461Ql}$	0.83
May	Exponential	$Qs=0.916e^{0.166Ql}$	0.80
June	Linear	$Qs=84.88Q_l-51.56$	0.98
July	Exponential	$Qs=0.062e^{0.641Ql}$	0.83
August	Exponential	$Qs=82.79\ e^{0.511Ql}$	0.86

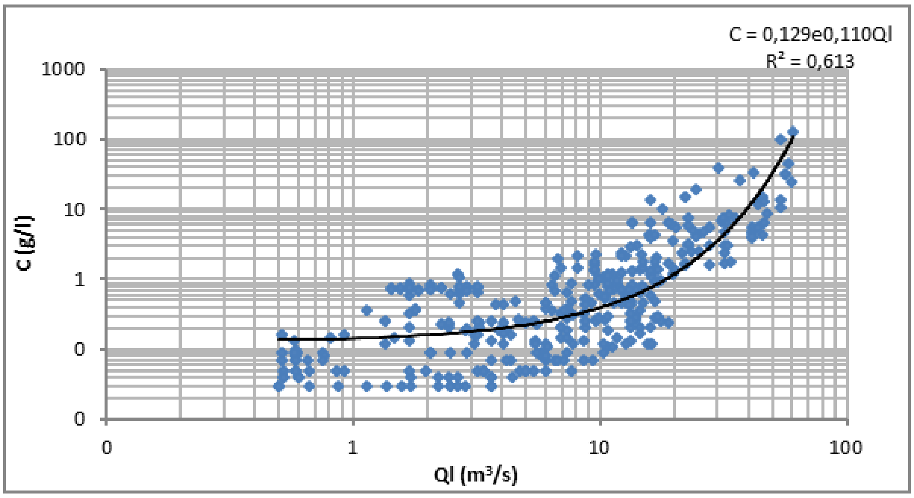

Figure 18. Suspended sediments-liquid flows variation: wet season in the Dehamecha basin

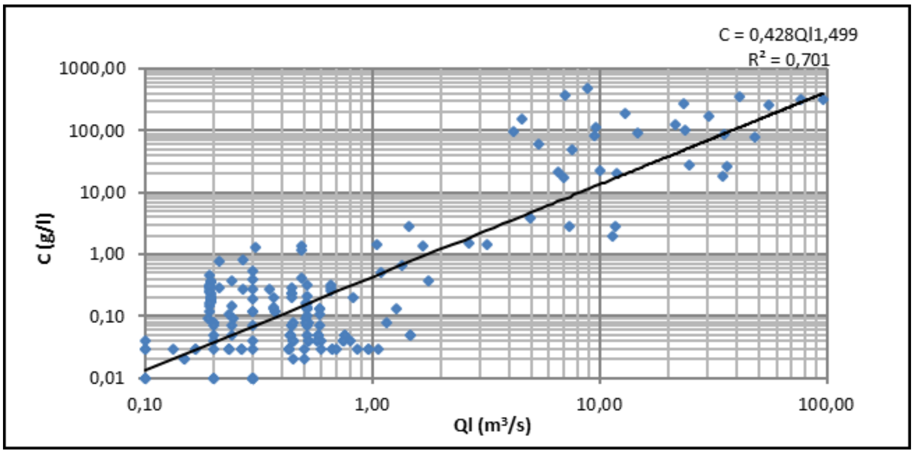

Figure 19. Suspended sediments-liquid flows variation: dry season in the Dehamecha basin

Visualization of all contents for suspended solids and liquid flows for wet season shows the power curve best trend with a correlation coefficient of about 0.61 (Fig. 18), while that of dry season, the power model is the most adequate with an excellent correlation of about 0.70 (Fig 19).

Solid inputs-liquid variation inputs

We have graphically represented the solid inputs evolution in relation to liquid flows, over a period of 30 years (Fig. 20).

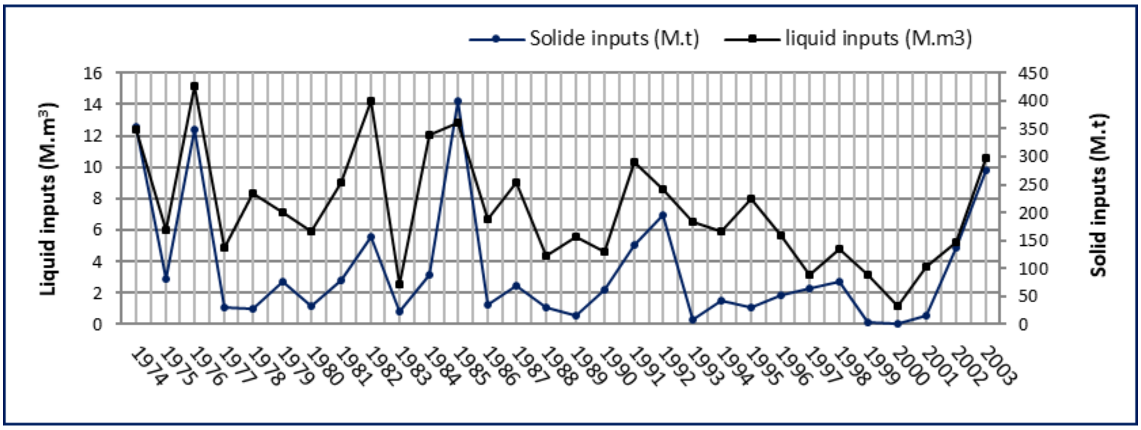

Figure 20. Solid inputs and liquid inputs evolution in the Dehamecha basin

The graphical analysis of solid flows evolution compared to liquid flows over a period of 30 years shows an almost subordinate variation of studied parameters (Q_S) and (Q_l). The important solid flows peaks can be

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explained by the floods occurrence contributing to the crossed lands erosion; and there for to the suspended sedimentary load increasing.

Erosion rate evaluation

While considering the total annual suspended solid transport Q_s (in tones/year), the average specific erosion over a period of 30 years, the specific erosion is calculated by the formula: $Es = Q_s/S$, where S is the area of the study area surface estimated at 3399 km^2, is estimated at 1030.05 t / km^2 (Fig. 21). We have been able to detect years that have formed the largest solid transport volumes: 1985, 1974, 1976, 2003, 1992, 1982, 1991 and 2002.

Emphasis of floods influence on suspended sediment export

Floods are known to play a major role in suspended sediment export [48]. The author defines the threshold $Q = Q_{avg} * 10$, which corresponds to 10 times the annual average liquid flow of period considered to estimate suspended sediment quantity exported during flood episodes. Graphical analysis of solid inputs variation for the two cases; with flood and without flood conditions, we have been able to determine the predominant role of these extreme events (floods) in the large sediment volumes export of Fig. 21.

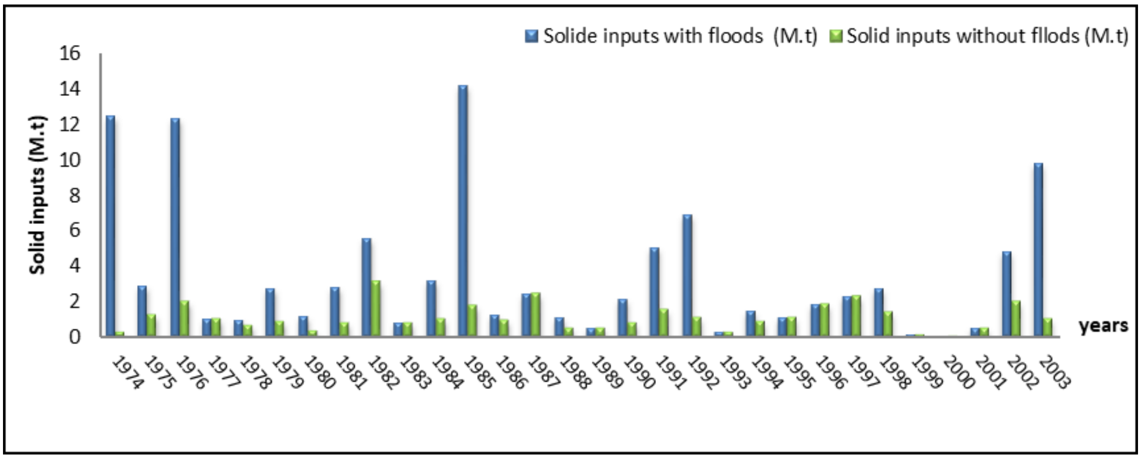

Figure 21. Floods influence on solid inputs annual rate in the Dehamecha basin

Meybeck [49] showed that 75% to 80% of suspended solid are transferred during floods. This reflects the existence of numerous suspended solid transport relays in the river system (low slopes, flood plain, and river bed). Indeed, it is during flood episodes that solid inputs in rivers are very significant. This justifies the fact that the years that have formed the largest volumes of suspended solid transport are those that have been marked by exceptional floods occurrence in volume and duration.

Influence of hydro-climatologic parameters on erosion

To follow specific erosion and some hydro-climatic parameters evolution as a function of time, we have highlighted the most significant indices of the specific erosion variation by a correlation analysis applied to the study area annual data.

Fig. 22, 23 and 24 respectively show the graphical analysis results of the pairs (specific erosion - maximum liquid flow, specific erosion - runoff, and specific erosion - rain), measured at both stations: Tassadane, and Chelgoum.

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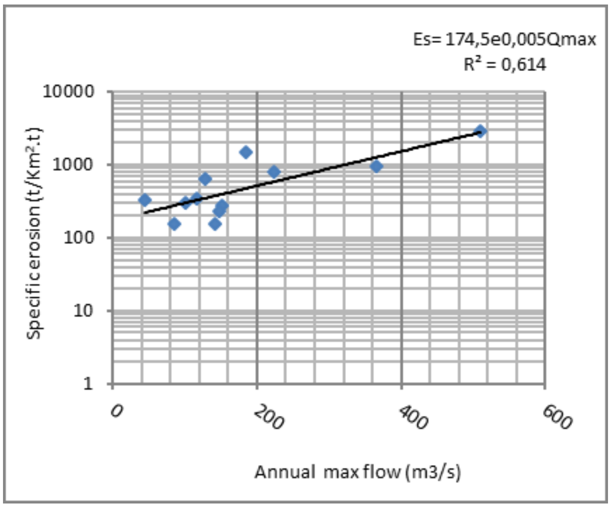

Figure 22. Relation: Specific erosion- annual max flow

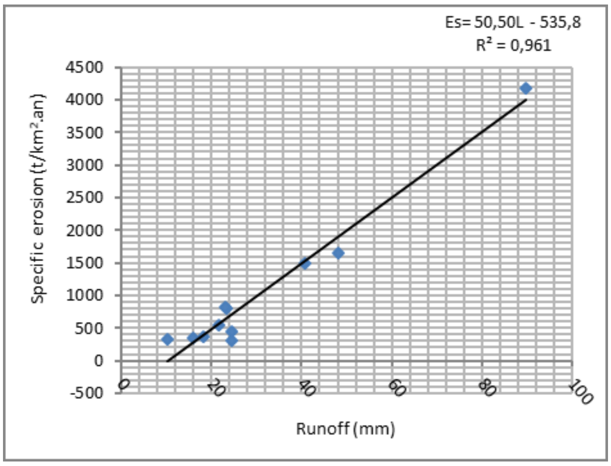

Figure 23. Relation: Specific erosion- runoff

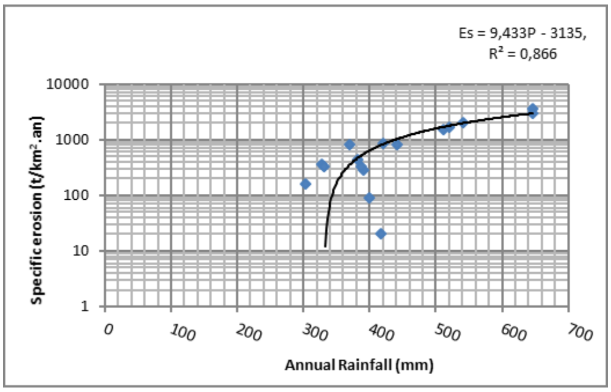

Figure 24. Relation: Specific erosion- annual rainfall

In general, the recorded maximum flow values present the irregular shape of floods causing a severe degradation of the crossed lands and thus, considered as causal factor of the most important solid contributions (Fig. 22).

- The specific erosion and runoff depth evolution confirm the runoff effects importance during extreme events (floods) in solid transport quantities increasing (Fig. 23).
- Rain is the source of energy required for particle removal, entrainment and destruction of aggregates and their transport. Annual rainfall is the most significant index of different precipitation characteristics (Fig. 24).

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7 CONCLUSION

Our study was dedicated to quantify the suspended solid inputs of the Endja watercourse draining the Dehamecha basin and to prevent some siltation of the Beni-Haroun dam reservoir. The watershed rainfall distribution analysis was of great importance as well as flows study to better understand the Endja watercourse regime variations.

The application of the Principal Component Analysis (PCA) method in the Dehamecha basin, equipped with seven rainfall stations, showed that El Koudiat station has the high vector value C_1 (0.89), so it is the representative station of the study area. The projection of station observations studied during the period 1970-2010 for the first vector C_1 made it possible to distinguish wet years (1977, 2003, 2005 and 2009) marked by the highest values of C_1, while the low values correspond to dry years (1983 and 1997).

For the seven studied stations in the study area, two periods were distinguished: a dry period corresponds to summer season (June, July and August) characterized by a marked rainfall deficit, a wet period corresponds to the rest of the year, this rainy period is also marked by a succession of wet months and relatively dry months. Monthly average rainfall is low in the north compared to south in the Dehamecha basin. The rainiest months are in winter (December and February) or in spring. This season recorded a rainfall ranging from 93 mm to 176 mm, while the driest are those of July and August recorded at Ain El kebch station. The dry climatic trend assumption of the past two decades is confirmed more by the almost general flow lack over the past seven years.

At an extreme flows scale: floods and low-flows which are the most important aspects characterizing the watercourse flow regime. The Tassadane gauging station recorded 38 floods in 30 years from 1973 to 2003, 18 of which in wet season. This type is generated by showers that are both long-lasting and extensive, sometimes affecting all or a large part of the study area, while the dry season floods (20 floods) are generally associated with brief and localized thunderstorms [37].

The two standard floods chosen have clearly defined the characteristics of each type of flood: the flood recorded from 3 to 4 February 1984 showed three rises of water (peaks) successively due to several successive showers, it counted a maximum flow of 366.20 m^3/s. Unlike the water rise, the water fall was much slower. The hydrograph of food recorded on 25 September 1973, which belongs to the hot season, was characterized by a brutality of the water rise as in wet season floods. The water fall was also fast because of the cessation of the rainfall after the flood peak and the weak support of the river flow on hot season.

Mathematical relation study via graphical analysis for the totality of observed data showed an excellent trend of the power curve, with a determination coefficient $R^2 = 0.83$ for the couple: Q_s-Ql; while for the couple: C-Ql, the exponential model is the most suitable for dataset with a determination coefficient $R^2 = 0.70$. A good correlation between the liquid flow and solid flow showed for wet season: an exponential trend with a determination coefficient of about 0.74, while for the dry season, the model power is the most adequate with a correlation of 0.79 (R^2).

The pair Qs-Ql was chosen for the quantification of solid transport due to the excellent correlation. The solid transport quantification is done on the basis of the monthly models found for the pair (Qs-Ql), for the two cases: solid flow with flood, and solid flows without flood (by elimination of flood volume), in order to predefine the extreme events role in solid inputs export. Solid inputs quantities comparison in both cases allowed to assess the floods predominant role in suspended sediments export and to show their direct effect on the inter-annual balance. In fact, the highest suspended sediment concentrations are restricted to flood episodes, which can reach up to 400 M. t per year.

The average specific erosion calculated for all area of the study area surface estimated (3399 Km^2) was estimated at 1030.05 t / km^2. We were able to detect years that have formed the largest solid transport volumes, i.e. 1985, 1974, 1976, 2003, 1992, 1982, 1991 and 2002 for a study period 30 years.

Several techniques to fight this phenomenon have been tested in many sites, but without having good results. This failure is mainly due to the lack of siltation mechanism control and solid materials quantity transported in watercourses and more particularly the solid fraction entering the reservoirs. Given the importance of this problem and data lack solid transport quantification is therefore essential [50].

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DOI 10.35180/gse-2019-0025

REFERENCES

[1] ASSELMAN, N. E. M. Fitting and interpretation of sediment rating curves. *Journal of Hydrology*. 2000, 234(3-4), 228-248. DOI: 10.1016/S0022-1694(00)00253-5

[2] SUN, G., S. G. MCNULTY., J. P. SHEPARD, D. M. AMATYA, H. RIEKERK, N. B. COMERFORD, W. S. KAGGS and J.R. SWIFT. Effects of timber management on the hydrology of wetland forests in the southern United States. *Forest Ecology and Management*. 2001, 143(1-3), 227-236. DOI: 10.1016/S0378-1127(00)00520-X

[3] VERSTRAETEN, G and J. POESEN. Factors controlling sediment yield from small intensively cultivated catchments in a temperate humid climate. *Geomorphology*. 2001, 40(1-2), 123-144. DOI: 10.1016/S0169-555X(01)00040-X

[4] WARD, A. D., D. ANDREW, A. D. JAYAKARAN, D. E. MECKLENBURG, G. E. POWELL and J. WITTER. Two-stage channel geometry: active flood plain requirements. In : *Encyclopedia of Water Science*. Taylor & Francis/CRC Press. 2008.

[5] EDER, A., P. STRAUSS, T. KRUEGER and J.N. QUINTON. Comparative calculation of suspended sediment loads with respect to hysteresis effects (in the Petzenkirchen catchment, Austria). *Journal of hydrology*. 2010, 389(1-2), 168-176. DOI: 10.1016/j.jhydrol.2010.05.043

[6] MÉTADIER, M. and K. J. L BERTRAND. The use of long-term on-line turbidity measurements for the calculation of urban stormwater pollutant concentrations, loads, pollutographs and intra-event fluxes. *Water research*. 2012, 46(20), 6836-6856. DOI: 10.1016/j.watres.2011.12.030

[7] PETIT, S. The pollinators of two species of columnar cacti on Curaçao, Netherlands Antilles. *Biotropica*. 1995, 27(4), 538-541.

[8] SICHINGABULA, H. M. Factors controlling variations in suspended sediment concentration for single-valued sediment rating curves, Fraser River, British Columbia, Canada. *Hydrological processes*. 1998, 12(12), 1869-1894.

[9] XU, J. Implication of relationships among suspended sediment size, water discharge and suspended sediment concentration: the Yellow River basin, China. *Catena*, 2002, 49(4), 289-307. DOI: 10.1016/S0341-8162(02)00064-4

[10] MEYBECK, M., L. LAROCHE., H. H. DÜRR and J. P. M. SYVITSKI. Global variability of daily total suspended solids and their fluxes in rivers. *Global and planetary change*. 2003, 39(1-2), 65-93. DOI: 10.1016/S0921-8181(03)00018-3

[11] STEEGEN, A., G. GOVERS, L. BEUSELINCK, J. NACHTERGAELE, I. TAKKEN and J. POESEN. Variations in sediment yield from an agricultural drainage basin in central Belgium. *IAHS publication*. 1998, 177-186.

[12] LENZI, M. A., A. MARIO and L. MARCHI. Suspended sediment load during floods in a small stream of the Dolomites (northeastern Italy). *Catena*. 2000, 39(4), 267-282. DOI:10.1016/S0341-8162(00)00079-5

[13] BOARDMAN, J. Soil erosion science: Reflections on the limitations of current approaches. *Catena*. 2006, 68(2-3), 73-86. DOI:10.1016/j.catena.2006.03.007

[14] GERICKE, A and M. VENOHR. Improving the estimation of erosion-related suspended solid yields in mountainous, non-alpine river catchments. *Environmental modelling & software*. 2012, 37, 30-40. DOI:10.1016/j.envsoft.2012.04.008

[15] VANMAERCKE, M., W. MAETENS, J. POESEN, B. JANKAUSKAS, G. JANKAUSKIENE, G. VERSTRAETEN and J. DE VENTE. A comparison of measured catchment sediment yields with measured and predicted hillslope erosion rates in Europe. *Journal of Soils and Sediments*. 2012, 12(4), 586-602. DOI: 10.1007/s11368-012-0479-z

[16] BERNOUX, M., C. C. CERRI, C. E. P. CERRI, M. SIQUEIRA NETO, A. METAY, A. S. PERRIN, E. SCOPEL, D. BLAVET and M. PICCOLO. Influence of direct seeding with vegetation cover on carbon sequestration and erosion in Brazil. Erosion Network Newsletter. 2004, 23, 323-337.

[17] ROOSE, E. J. Use of the universal soil loss equation to predict erosion in West Africa. In: Soil erosion: prediction and control. *Soil Conservation Society of America Ankeny*, IA. 1977. 60-74.

[18] CASENAVE, A. and C. VALENTIN. Surface states of the Sahel zone: influence on infiltration. [online] 1989 [cit. 2019-05-20] Available from: *http://www.documentation.ird.fr/hor/fdi:27816*.

[19] OLD, G. H., D. M. LAWLER and A. SNORRASON. Discharge and suspended sediment dynamics during two jökulhlaups in the Skaftá river, Iceland. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group*. 2005, 30(11), 1441-1460.

[20] VERICAT, D. and R. J. BATALLA. Sediment transport in a highly regulated fluvial system during two consecutive floods (lower Ebro River, NE Iberian Peninsula). *Earth Surface Processes and Landforms. The Journal of the British Geomorphological Research Group*. 2005, 30(4), 385-402.

[21] TENA, A., R. J. BATALLA., D. VERICAT and J. A. LÓPEZ-TARAZÓN. Suspended sediment dynamics in a large regulated river over a 10-year period (the lower Ebro, NE Iberian Peninsula). *Geomorphology*. 2011, 125(1), 73-84. DOI: 10.1016/j.geomorph.2010.07.029

[22] HALLOT, E., M. BENOIT, G. STASSE, F. BOULVAIN, L. LECLERCQ, F. PETIT and E. JUVIGNE. Silting of the Butgenbach lake reservoir (Ardenne, Belgium). *Société géographique of Liège Newsletter.* 2012, 59, 39-57.

[23] HOROWITZ, A. J. An evaluation of sediment rating curves for estimating suspended sediment concentrations for subsequent flux calculations. *Hydrological processes*. 2003, 17(17), 3387-3409. DOI: 10.1002/hyp.1299

[24] MOREHEAD, M. D., J. P. SYVITSKI, E.W.H. HUTTON and S.D PECKHAM. Modeling the temporal variability in the flux of sediment from ungauged river basins. *Global and Planetary change*. 2003, 39(1-2), 95-110.

[25] MOATAR, F. and J. GAILHARD. Water temperature behaviour in the River Loire since 1976 and 1881. *Comptes Rendus Geoscience*. 2006, 338(5), 319-328.

[26] ROVIRA, A. and R. J BATALLA. Temporal distribution of suspended sediment transport in a Mediterranean basin: The Lower Tordera (NE SPAIN). *Geomorphology*. 2006, 79(1-2), 58-71. DOI: 10.1016/j.geomorph.2005.09.016

[27] DUMAS, D. The results of 10 years of daily observations of the flux of suspended matter in one of the main watercourses in the European Alps: The Isere at Grenoble (France). *Comptes Rendus Geoscience*. 2007, 339(13), 810-819.DOI: 10.1016/j.crte.2007.09.003

[28] LEFRANÇOIS, J., C. GRIMALDI, C. GASCUEL-ODOUX and N. GILLIET. Suspended sediment and discharge relationships to identify bank degradation as a main sediment source on small agricultural catchments. *Hydrological Processes: An International Journal*. 2007, 21(21), 2923-2933.

[29] THODSEN H., B. HASHOLT and J.H. KJÆRSGAARD. The influence of climate change on suspended sediment transport in Danish rivers. *Hydrological Processes: An International Journal*. 2008, 22(6), 764-774. DOI: 10.1002/hyp.6652

[30] PICOUET, C., B. HINGRAY and J. C. OLIVRY. Modelling the suspended sediment dynamics of a large tropical river: The Upper Niger River basin at Banankoro. *Hydrological Processes: An International Journal*. 2009, 23(22), 3193-3200. DOI: 10.1002/hyp.7398

[31] FURUICHI, T., Z. WIN and R. J. WASSON. Discharge and suspended sediment transport in the Ayeyarwady River, Myanmar: centennial and decadal changes. *Hydrological Processes: An International Journal*. 2009, 23(11), 1631-1641.

[32] MANO, V., J. NEMERY, P. BELLEUDY and A. POIREL. Assessment of suspended sediment transport in four alpine watersheds (France): influence of the climatic regime. *Hydrological Processes: An International Journal*. 2009, 23(5), 777-792. DOI: 10.1002/hyp.7178

[33] MARTTILA, H. and B. KLOVE. Dynamics of erosion and suspended sediment transport from drained peatland forestry. *Journal of hydrology*. 2010, 388(3-4), 414-425. DOI: 10.1016/j.jhydrol.2010.05.026

[34] ARAUJO, H. A. et al. Estimating suspended sediment concentrations in areas with limited hydrological data using a mixed-effects model. *Hydrological Processes*. 2012, 26(24), 3678-3688. DOI: 10.1002/hyp.8462

[35] GAO, P. and M. JOSEFSON. Temporal variations of suspended sediment transport in Oneida Creek watershed, central New York. *Journal of Hydrology*. 2012, 426, 17-27. DOI: 10.1016/j.jhydrol.2012.01.012

[36] TRICART, J. Discontinuities in erosion processes. *Bulletin of the International Association of Hydrologic Sciences*. 1962, 59, 33-43.

[37] DEMMAK, A. *Contribution to the study of erosion and solid transport in northern Algeria*. Dissertation. University of Paris, France. 1982, 323 p.

[38] ROCHE, M. Chapter VIII: Floods of large and medium basins. *Surface hydrology, ORSTOM Paris, France*. 1963, 289-291.

[39] GHENIM, A., A. TERFOUS and A. SEDDINI. Study of suspended solid transport in semi-arid Mediterranean regions: case of the watershed of Sebdou wadi (North-West Algeria). *Science et changements planétaires/ Sécheresse*. 2007, 18(1), 39-44.

[40] BOUANANI, A., K. BABA-HAMED and W. FANDI. Production and transport of suspended sediment in Sikkak wady (Tafna – North West Algeria). *Journal of Water Science*. 2013, 26(2), 119-132. DOI: 10.7202/1016063ar

[41] TOUAT, S. Control of the representativity of the sample of suspended solid transport. *Water and soil review of Algeria.* 1989, 2, 48–54

[42] BOUROCHE, J.M. and G. SAPORTA. *Data analysis*. Paris: Presses Universitaires de France. 1980.

[43] PETELET, G. E. and P.H. NEGREL. Suspended matter supply to the Mediterranean Sea: assessment and key role of floods from the Hérault watershed (South France). *Techniques Sciences Méthodes*. 2007, 10, 55-69.

[44] WALLING, D. E., B. W. WEBB and J. C. WOODWARD. Some sampling considerations in the design of effective strategies for monitoring sediment-associated transport. *Erosion and sediment transport monitoring programmes in river basins*. 1992, 210, 279-288.

[45] ANSARI, A. A., I. B. SINGH and H. J. TOBSCHALL. Importance of geomorphology and sedimentation processes for metal dispersion in sediments and soils of the Ganga Plain: identification of geochemical domains. *Chemical Geology*. 2000, 162(3-4), 245-266. DOI: 10.1016/S0009-2541(99)00073-X

[46] PONT, D., J. P. SIMONNET and A. V. WALTER. Medium-term changes in suspended sediment delivery to the ocean: consequences of catchment heterogeneity and river management (Rhône River, France). *Estuarine, Coastal and Shelf Science*. 2002, 54(1), 1-18.DOI: 10.1006/ecss.2001.0829

[47] EYROLLE, F., S. CHARMASSON and D. LOUVAT. Plutonium isotopes in the lower reaches of the River Rhone over the period 1945–2000: fluxes towards the Mediterranean Sea and sedimentary inventories. *Journal of environmental radioactivity*. 2004, 74 (1-3), 127-138. DOI: 10.1016/j.jenvrad.2004.01.017

[48] SERRAT, P., W. LUDWIG, B. NAVARRO and J. L. BLAZI. Spatial and temporal variability of sediment fluxes from a coastal Mediterranean river: The Têt (France). *Proceedings of the Academy of Sciences-Series IIA -Earth and Planetary Science*. 2001, 333(7), 389-397.

[49] MEYBECK, M. Man and river interface: multiple impacts on water and particulates chemistry illustrated in the Seine river basin. In: AMIARD, JC., B. LE ROUZIC, B. BERTHET and G. BERTRU (eds). *Oceans, Rivers and Lakes: Energy and Substance Transfers at Interfaces*. Developments in Hydrobiology, Vol 131. Dordrecht: Springer, 1998. DOI: https://doi.org/10.1007/978-94-011-5266-2_1

[50] VAN, C., J. DENIS, A. E. HALLOT, G. HOUBRECHTS, A. PEETERS, Y. LEVECQ, P. GÉRARD and F. PETIT. Suspended sediment flow in the rivers of the Meuse basin: proposal for a regional typology based on the specific denudation of watersheds *Bulletin of the Geographical Society of Liège.* 2013, 61, 15-36.